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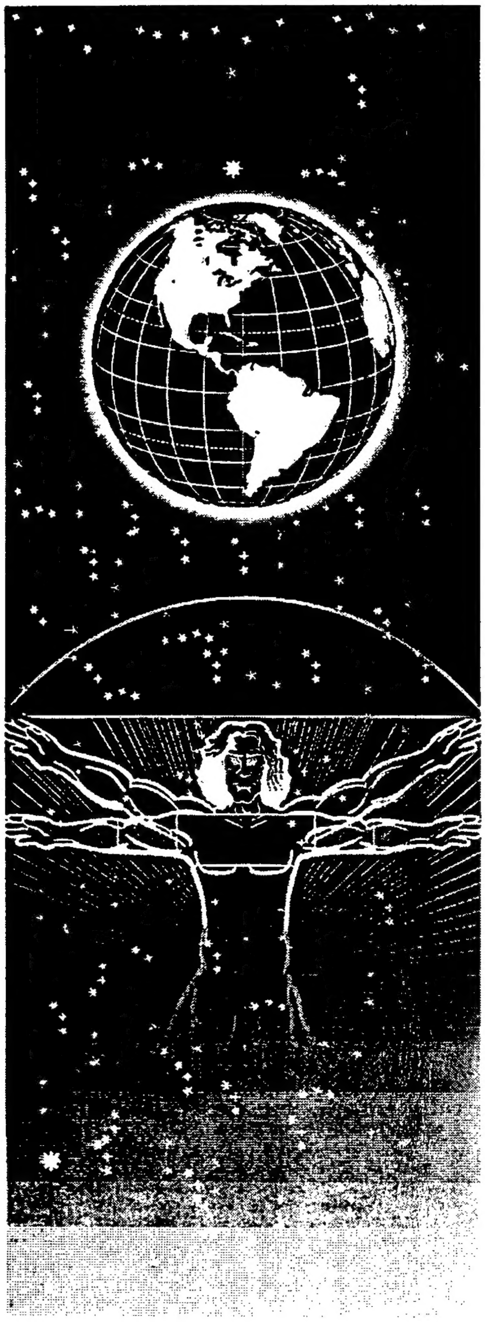

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INTEGRATED MEDICAL ENVIRONMENTS AND THE VIRTUAL REALITY PATIENT

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Northrop Grumman and Ethicon Endo-Surgery, along with Armstrong Laboratory's Aircrew Training Research Division, are developing prototype training systems to assist surgeons in triage assessment and in procedures for battlefield casualty management. The goal is to develop an integrated training system built around three major components: (a) a Biomedical Instructional Systems Decision Support System (BISD DSS) to characterize training tasks and set instructional objectives and performance standards; (2) a simulation based on the Precepter™ virtual reality patient to support training for battlefield wound diagnosis and laparoscopic surgery; and (3) an intelligent tutoring system hosted on Precepter™ to teach decision making skills for battlefield wound diagnosis and subsequent laparoscopic procedures.

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PREFACE

This paper documents a joint research effort performed under a Cooperative Research and Development Agreement (CRDA-93-014-AL-1) between Northrop Grumman and Armstrong Laboratory's Aircrew Training Research Division (AL/HRA). The work was conducted with Ethicon Endo-Surgery, Inc. to develop prototype simulation systems to help train surgeons in triage assessment and procedures for battlefield casualty management. This effort is documented under Work Unit 1123-B2-15, Synthetic Environments for Air Warrior Training Research; Work Unit Monitor was Dr Herbert H. Bell.

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Integrated Medical Environments and the Virtual Reality Patient

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ABSTRACT

Training today's surgical team has much in common with training the operators and maintainers of today's aerospace systems. In both cases, individuals must assess the situation, perform high skilled activities, and rapidly adjust as situations change. The military and aerospace communities have successfully developed and implemented tools and techniques for such training. This investment has produced significant advances in training system design, realistic training simulations, and artificial intelligence (cognitive task analysis and expert systems). These same technologies will also improve training for biomedical personnel.

Northrop Grumman and Ethicon Endo-Surgery, with assistance from the Armstrong Laboratory, are developing prototype simulation systems. This application will help train surgeons in triage assessment and procedures for battlefield casualty management. The goal is to develop an integrated training system built around three major components: (1) A Biomedical Instructional Systems Decision Support System (B ISD DSS) to characterize training tasks, set instructional objectives and performance standards. (2) A simulation based on the PreCeptor TM virtual reality patient to support training for battlefield wound diagnosis and laparoscopic surgery. (3) An intelligent tutoring system hosted on PreCeptor TM to teach decision making skills for battlefield wound diagnosis and subsequent laparoscopic procedures.

Prototype development is currently underway using PreCeptor TM. The prototype focuses on diagnostic and therapeutic procedures. Instructional content focuses on diagnosis, pre-operative preparation, laparoscopic surgery, and post-operative care.

INTRODUCTION

Several training technologies from the military and aerospace are identified for their direct application to surgical environments. Specifically, decision support systems, conceptual graph analysis, and expert systems are discussed as to their relationship to training in virtual reality. With new and adapted methodologies from the field of artificial intelligence (cognitive task analysis and expert systems) it is now possible to teach both surgerical skills and decision making, as applied to laparoscopic surgery. The virtual reality patient, PreCeptor TM, will be developed to host content for battlefield triage wounds. Previous PreCeptor TM content was associated with diagnosis, pre-operative preparation, laparoscopic surgery, and post-operative care. Virtual reality as a training medium for surgery holds promise to enhance and expand traditional ways of teaching medicine.

MILITARY AND AEROSPACE INVESTMENT IN MEDICINE

Prior to World War II the need to create a structured approach to develop and implement training systems was recognized, but no standardized approach existed until the 1960's. At that time procedures known as Instructional Systems Development (ISD) were established to provide a more structured approach to training. These ISD procedures have been adopted by the United States Army, Navy, and Air Force for weapon systems such as: M-1 Battle Tank, Polaris Missile, and B-2 Bomber. Over time, additional methods and models were created to support ISD throughout all phases of the weapon acquisition process (Babbitt, Bolstad, Craft, Semple, and Sparks, 1989).

Early versions of media selection models did not provide estimates of training effectiveness. Computational power was limited for ISD models, and models were designed to analyze small increments of the ISD process. New technical approaches were developed to select instructional media early in the ISD process. Evolution of media mix allocation models expanded the methodology so that metrics of both cost and training effectiveness were included by the 1970's (Sticha, Blacksten, Knerr, Morrison, and Cross, 1986).

During the 1980's military and aerospace interest in computer based training expanded to include technologies from artificial intelligence. Initially the artificial intelligence (AI) applications were simulation based, but did not incorporate training. For example, ADEPT aided battlefield situation assessment analysts by providing tactical interpretations of intelligence sensor reports. ADEPT was a research prototype. Another research prototype developed by Science Applications, Inc. was known as Ocean Surveillance. This system helped naval personnel aboard a surveillance ship to determine a remotely sensed vessel's destination and mission. Ocean Surveillance used information about the vessel's correlated tracks, history, location, and status to determine its likely destination, arrival time, and probable mission.

In the 1990's the Human Systems Advanced Technology (HSAT) project, Cooperative Research and Development Agreement, between Northrop

Grumman and USAF, Armstrong Laboratory, started adapting ISD and AI training technologies for application to aviation. Subsequently, these technologies were applied to surgical simulation in conjunction with Ethicon Endo-Surgery. The technologies have roots in military training, instructional systems development (ISD), artificial intelligence (AI), and simulation.

ISD AND AI TECHNOLOGY MIGRATION TO VIRTUAL REALITY

Three technologies which have been used in the HSAT project to develop aerospace training systems are being applied to medical training. The three technologies are: (1) decision support systems, (2) conceptual graph analysis, and (3) expert systems.

Decision Support Systems - Instructional Systems Development (ISD) Decision Support Systems (DSS) have traditionally been used by the military and aerospace for front-end analysis of training requirements. According to Babbitt, Sorensen, and Stubbs (1995), ISD decision support systems are an aid that helps the human decision maker generate questions and answers about a proposed training system before it is designed and programmed. Decision support systems answer questions such as what tasks must be trained, and what performance levels must tasks be trained to.

The Joint Service Instructional Systems Development/Aircrew Training Decision Support System (JS ISD/AT DSS) was developed as a front-end analysis tool to structure an aircrew training system. It includes the capability to identify clusters of tasks for cognitive task analysis, and assists instructional designers in the design and development of aircrew training systems (Babbitt, Sorensen, Vreuls, Obermayer, Muckler, and Gordon, 1994). Since JS ISD/AT DSS contains many generic modules and high degrees of decision making are required both in aviation and medicine, it was decided to convert the aircrew training decision support system into a biomedical decision support system.

The Biomedical Instructional Systems Development Decision Support System (B ISD DSS) contains similar modules found in JS ISD/AT DSS. These modules were adapted to a surgical application. Of particular interest is the cognitive rating scale where cognition is scaled on 22 cognitive abilities. Cognitive scaling allows identification of high level decision making tasks associated with surgeon activities before, during, and after surgery. Figure 1, Cognitive Abilities Rating Scale Adapted from B ISD DSS, shows a sample of 10 of the 22 cognitive abilities mentioned above. Each cognitive ability is rated on a scale from 1 through 7 using the automated decision support system. Cognitive abilities identified on this scale during task analysis are clustered by scale points between 1 and 7. Cut off scores of 6 and 7 have been used to identify and cluster tasks for further analysis known as cognitive task analysis.

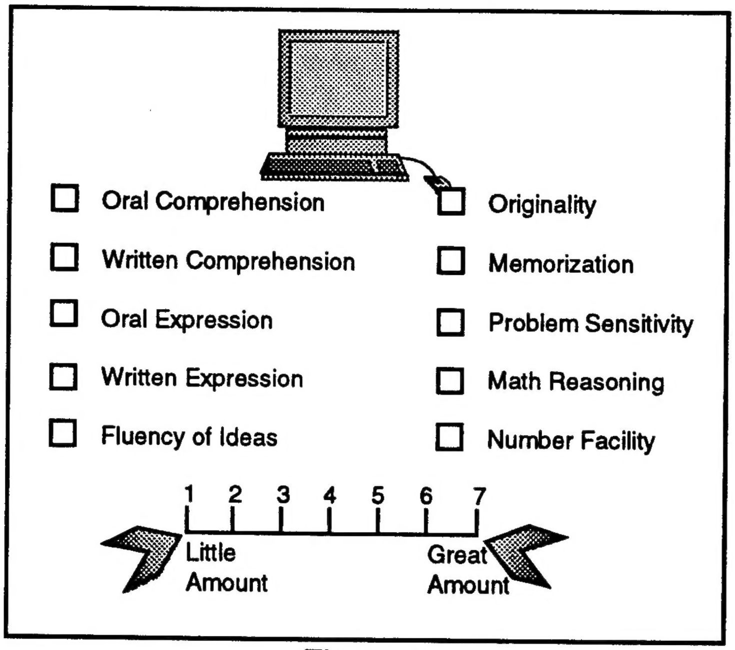

Figure 1.
Cognitive Abilities Rating Scale
Adapted from B ISD DSS

Cognitive Task Analysis - Cognitive task analysis focuses on the knowledge necessary to select tasks which represent mental activity such as problem solving, whereas, task analysis focuses on the procedures needed for successful task performance. Tasks requiring extensive decision making are further analyzed using cognitive task analysis (CTA). CTA has been used in aviation to build intelligent flight simulation scenarios. It became apparent that CTA had a role to play in medicine as well due to the similarities between aircrews and surgical teams where high levels of decision making are required within time compressed conditions (cockpit and surgical suite). Cognitive task analysis represents knowledge in object hierarchies. Object hierarchies display relationships among higher-level objects and lower level objects. Several cognitive models exist such as Bloom's cognitive taxonomy where the cognitive domain is divided into six main categories: knowledge, comprehension, application, analysis, synthesis, and evaluation (Fleishman and Quaintance,1984).

Another version of CTA comes from Papantonopoulos and Salvendy (1993), where cognitive task allocation can be defined as the phase in the design of primarily cognitive tasks determining which functions are to be performed by the various system components. They refer to the human operator or the computer in their application. In our particular project the system components include the surgeon (human operator), equipment (includes hardware and software), laparoscopic instruments, and simulated anatomical structures of the patient.

Several methods have been created to conduct a formal CTA. These methodologies have been adapted from the field of artificial intelligence, and are known as knowledge elicitation and knowledge representation. Conceptual

graph analysis is a knowledge elicitation and representation tool for general knowledge acquisition that supports the instructional designer. It is an important way to represent decision making.

Conceptual graph analysis (CGA) is used to represent knowledge structuring around large, complex databases. It provides a means of representing concepts and their relationship to support the performance of human cognitive activities. Instructional designers use conceptual graph analysis to identify the information content of the system, represent the format of the information within the system, and the means by which the user will access the information. Conceptual graph analysis users perform a systematic querying technique called question probes with a graphical notation system called conceptual graph structures.

According to Gordon, Kinghorn, and Schmierer (1991), conceptual graph analysis represents three types of knowledge: (1) verbalizable semantic knowledge, (2) verbalizable rule/procedure knowledge, and non-verbalizable implicit knowledge. Through knowledge elicitation all three types of knowledge are represented in a conceptual network containing nodes and arcs. Content of the nodes is classified as either a Concept, State, Event, Style, Goal, or Goal/Action. Arcs between nodes represents the relationship between nodes. Graphs tend to have subclusters containing certain taxonomic structures. Table 1 is an illustration of a CGA adapted from Gordon, Kinghorn, and Schmierer, (1991). Table 1 represents node categories and arc labels for goal/hierarchy structures. Conceptual graph analysis representation could be applied to surgery. For example, the source node might have the goal to rotate a laparoscopic stapler clockwise and counterclockwise. The arc would represent the reason for the stapler rotation such as to observe that there is no other tissue in the stapler. The terminal node goal might represent stapler firing the staples without the ureter being in the stapler.

Source Node	Arc	Terminal Node	Arc Definition
Goal, Goal/Action	Reason	Goal Goal/Action	Terminal node is reason, motive, or superordinate node for source node.
Goal, Goal/Action Event, State, Style	Means Initiate	Goal/Action Goal, GoalAction	Source node initiates or triggers the terminal node.
Goal/Acquition	Consequence	Event, State, Style	Source node causes or enables terminal node or precedes terminal node.

Table 1.
Node Categories and Arc Labels
for Goal/Hierarchy Examples

Expert Systems - Conceptual graph analysis forms the foundation for programming expert system surgical simulation. Node, arc, and goal/hierarchies formed into clusters to describe cognitive structures are used to construct a rule based system. Cognitive strutures are also used to design instructional content. The domain under investigation was for a biomedical version of a surgical training system. In this system the expert system performs the same role as the surgical expert.

Figure 2 displays a diagram of the knowledge engineering process where the surgeon's knowledge is transferred to a computer program. To make the expert system intelligent requires high-quality, specific knowledge about the surgerical domain. The knowledge is obtained through medical texts, interviews, video tapes, and observation. The computer program is designed to solve problems in much the same way as the expert surgeon.

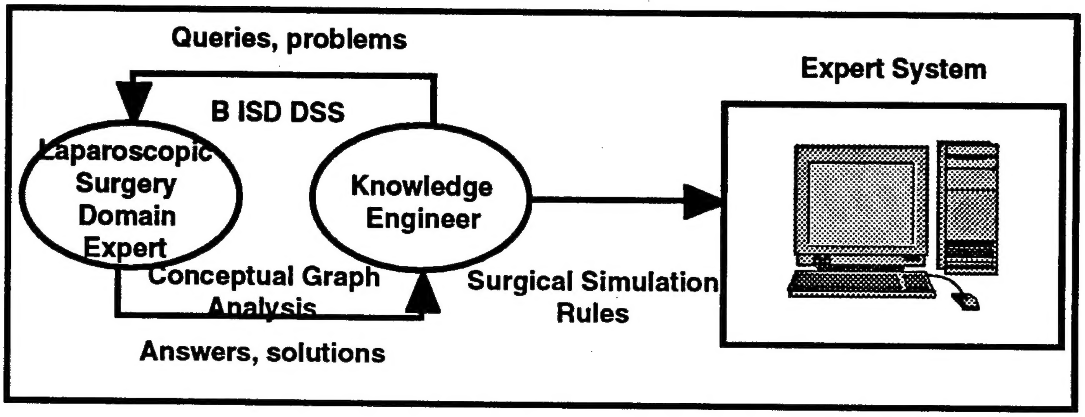

Figure 2.
Knowledge Engineering Transfers Surgical Knowledge to Expert System Software Program

The computer program uses an expert system shell to build the laparoscopic surgery domain rule base. The expert system shell contains a database structure to hold the laparoscopic surgical data which the program rules access and operate on. An inference engine processes the rules to generate surgical answers and solutions. Interfaces are provided to enable rule modification, and to test rule sets. In summary, the expert system contains the laparoscopic surgery database, an inference engine with surgical rules (obtained from CTA), and an interface for the programmer.

Expert system shells are interfaced with a dynamic model of the anatomy. Anatomical simulation requires modeling interrelationships between anatomical objects. System responses to external events, and sequences of interactions to be programmed are described in software event flow diagrams. Event flow diagrams are used to describe surgical vignettes of typical interaction sequences. Multiple software programs are interfaced in order to create an intelligent surgical simulation.

INTELLIGENT VIRTUAL PATIENT ENVIRONMENT (IVPE)

IVPE - Signifies the next generation surgical simulator with application to battlefield wounds. Several medical lessons learned through Operations Desert Shield and Desert Storm called for improving medical readiness according to the "Medical Readiness Strategic Plan: 1995 - 2001." The plan calls for the inclusion of medical requirements in all wargaming activities. DoD has determined that shortfalls exist in medical readiness training in the Active and Reserve medical forces across all military services. IVPE provides an opportunity for specialty surgical skill sustainment within a battlefield context.

SUMMARY

Technologies identified for Instructional Systems Development Decision Support Systems (ISD DSS), Cognitive Task Analysis, Conceptual Graph Analysis, Expert systems, an PreCeptorTM all played a role in bringing lessons learned into surgical simulation.

In summary, the B-2 Division, Northrop Grumman, used an aircrew version of the decision support system to analyze upgrades to the B-2 bomber aircrew member training. PreCeptorTM development for Ethicon Endo-Surgery included analysis of surgeon abilities and decision making with the cognitive rating scales found in B ISD DSS. PreCeptorTM lessons learned were useful in conceptualizing the structure of vignettes which will be hosted on the PreCeptorTM surgical simulator. A form of cognitive task analysis known as conceptual graph analysis combined with expert systems was used to structure an F-16 intelligent flight simulation for the USAF, Armstrong Laboratory, and Northrop Grumman. Technologies combined in new applications with previous lessons learned will be employed on IVPE.

REFERENCES

Babbitt, B. A., Bolstand, C. A., Craft, C. J., Semple, C. A., and Sparks, R. J. (1989). Assessment of cost and training effectiveness analysis (CTEA) models. NOR 89-100, IR&D Project No 89-D-2500. Hawthorne, CA: Northrop Corporation.

Babbitt, B. A., Sorensen, H. B., and Stubbs, J. (June, 1995). Decision support systems and surgical training in a virtual reality environment. Virtual Reality in Medicine and Developers' Expo Proceedings. Cambridge, Massachusetts.

Babbitt, B. A., Sorensen, H. B., Vreuls, D., Obermayer, R. W., Muckler, F. A., and Gordon, S. E. (1994). Human systems advanced technology: Advanced training systems development. In G. E. Bradley and H. W. Hendrick (Eds.). Human factors in organizational design and management - IV. (pp. 359-364). Amsterdam, The Netherlands: North-Holland.

Fleishman, E., and Quaintance, M. K. (1984). Taxonomies of human performance. Academic Press: New York.

Gordon, S. E., Kinghorn, R. A., Schmierer, K. A. (1991). Representing expert knowledge for instructional system design: A case study. Proceedings of the Human Factors Society 35th Annual Meeting.

Medical Readiness Strategic Plan: 1995 - 2001. (March, 1995). Department of Defense: Washington, D.C.

Papatonopoulos, S.A., and Salvendy, G. (1993). A decision model for cognitive task allocation. Designing for Diversity, Vol. 1. Seattle, Washington: Proceedings of the Human Factors and Ergonomics Society, 37th Annual Meeting.

Sticka, P. J. Blacksten, H. R, Knerr, C. M., Morrison, J. E., and Cross, K. E. (1986). Optimization of simulation-based-training-systems: Final Report No. 86-13. Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Waterman, D. A. (1985). A guide to expert systems. Menlo Park, California: Addison-Wesley Publishing Company.